



Full Length Article

Impact of injection pressure on CO₂-enhanced coalbed methane recovery considering mass transfer between coal fracture and matrix



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HIGHLIGHTS

- Results of coal core flooding tests under different injection pressure are presented.
- The influence of the mass transfer rate on the production efficiency is investigated.
- The mass transfer rate and the dispersion coefficient are affected by the injection pressure.

ARTICLE INFO

Article history:

Received 13 September 2016

Received in revised form 5 December 2016

Accepted 1 February 2017

Available online 10 February 2017

Keywords:

CO₂-ECBM recovery

Core flooding experiment

Injection pressure

Mass transfer

Production efficiency

ABSTRACT

Although the production mechanism of CO₂-enhanced coalbed methane (ECBM) recovery has been previously reported and corresponding models have been proposed, investigations on the effect of the injection pressure on the production efficiency considering the mass transfer between the coal fracture and matrix are lacking. In this study, laboratory core flooding experiments were conducted on the coal sample from South Sichuan Basin, China. Experimental results indicate that earlier breakthroughs and a higher initial CH₄ flow rate and cumulative CH₄ flow rate occurred under a higher injection pressure in the CO₂-ECBM recovery. However, as CO₂ was continuously injected, the CH₄ flow rate and cumulative CH₄ flow rate under a lower injection pressure exceeded those at the higher injection pressure. Furthermore, a dual porosity model was used to perform numerical simulations. The simulation results under four injection pressures matched the experimental results well. The simulation results indicate that the dispersion in fractures and the mass transfer rate between matrices and fractures significantly affect the CH₄ flow rate. The injection pressure leads to changes in the experimental observations by affecting the dispersion and the mass transfer rate.

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1. Introduction

Coalbed methane (CBM) is an unconventional gas resource that accounts for approximately 6–9% of the current natural gas production [1]. Gas releases can influence the coal permeability and reservoir pressure [2]. During conventional CBM recovery, the reduction of the reservoir pressure leads to a rapid decrease in the CH₄ recovery rate. The production efficiency of conventional CBM recovery is not economical, especially in the late stage. Therefore, gas-enhanced coalbed methane (ECBM) recovery is an effective method for increasing the production.

In previous studies, nitrogen (N₂), carbon dioxide (CO₂), and flue gas were used as injectants to displace CBM. Mazumder et al. [3]

reported that different injectants provided different displacement efficiencies. Van et al. [4] confirmed that the breakthrough time increased with the sorption capacity of the injectants. Wei et al. [5] used a new numerical approach to investigate the mixed gases enhanced coalbed methane. It was found that the injection gas composition had a significant effect on produced gas composition. Zhou et al. [6] compared the results of CO₂ and N₂ ECBM experiments and reported that CO₂ injection reduced the coal permeability whereas N₂ injection enhanced the coal permeability. Dutka et al. [7] employed 10 manometers to measure the pore pressure depression along a briquette. They found a clearly separated zone with mixed CO₂ and CH₄. Jessen et al. [8] and Wang et al. [9] measured the gas composition along a coal pack and discovered that CO₂ displacing CH₄ became nearly piston-like. Shi et al. [10] reported a bidisperse pore-diffusion model for the competitive displacement between adsorbed CH₄ and CO₂ that matched data from a core-flush test well. Connell et al. [11] and Sander et al. [12]

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reported numerical simulations that matched the results of core flooding experiments. Liu et al. [13] used a dual poro-elastic model to simulate CO₂-ECBM recovery. Simulation results indicated that CO₂ injection increased the cumulative production of CH₄ in proportion to the injection pressure.

Considering the higher affinity of CO₂ to coal mass than pre-adsorbed CH₄, coal seams have potential for the geological sequestration of CO₂. Therefore, CO₂-ECBM recovery can reduce the global greenhouse effect. CO₂-ECBM recovery projects require a large and long-term investment. Perera et al. [14] reported that the adsorption of CO₂ into the coal matrix have a significant impact on the chemical and physical structure of coal. Their later research [15] indicated the long-term injection of CO₂ can affect the coal seams and other adjacent rock strata. Before a CO₂-ECBM recovery project is implemented, the migration mechanism of the multicomponent gas in the coal seams must be investigated to reduce the economical and technical risk and provide a theoretical basis for the CO₂-injection strategy.

Studies have reported the influence of the injection intensity on the production efficiency for miscible displacement in CO₂-enhanced gas recovery (EGR) and CO₂-enhanced oil recovery (EOR). Sim et al. [16] determined that a higher injection velocity results in a higher efficiency of CH₄ recovery in sand packs. Abdullah et al. [17] investigated natural-gas displacement by supercritical CO₂ and found that faster displacement yielded a better sweep efficiency and later breakthroughs in sandstone. In contrast to a homogeneous medium, Babadagli et al. [18] used sandstone and limestone, which spanned an artificial fracture between injection and production ends, to simulate CO₂-EOR in naturally fractured reservoirs. They determined that the efficiency of CO₂-EOR was higher with a lower CO₂ injection velocity.

For CO₂-ECBM projects, Vishal et al. [19] reported the production of coalbed methane is affected by the in situ gas content, the thickness of the coal seams, the permeability and the sorption behavior of coal. Perera et al. [20] conducted a study on CO₂ sequestration in Victorian brown coal and reported that the migration of CO₂ in coal seams depends on three factors: coal mass properties, seam permeability and gas sorption properties of coal. Merkel et al. [21] investigated the competitive sorption behavior of CH₄ and CO₂ can be affect by the coal rank.

In the present study, we examined the impact of the injection pressure on CO₂-ECBM recovery by considering the mass transfer between the coal fracture and the matrix. Core flooding experiments for naturally fractured anthracite at different injection pressures were designed to simulate the processes of CO₂-ECBM recovery and conventional CBM recovery. In addition, numerical simulations were conducted to verify the experimental results. Experimental results and numerical simulations were combined to investigate the influence of the injection pressure on the production efficiency of CO₂-ECBM recovery by considering the mass transfer between matrices and fractures. The results provide a theoretical basis for a strategy for CO₂ injection in different periods of CO₂-ECBM recovery to obtain the optimal CH₄ production efficiency.

2. Core flooding experiments

2.1. Experimental setup and testing procedure

Core flooding experiments were performed using a self-developed triaxial servo-controlled equipment for thermo-hydro-mechanical coupling of coal containing CH₄ [22]. Fig. 1 shows a schematic of the apparatus, which is divided into two parts. Part 1 comprises the hydraulic stress triaxial cell and temperature control unit. Part 2 comprises the gas injection and recovery unit, which includes the gas sources of CH₄ and CO₂ (the purity of CH₄ and CO₂ used in the experiments was $\geq 99.99\%$). The upstream and downstream flow rates were measured using two flowmeters with a precision of 1 mL/min. The upstream and downstream gas pressures were measured using two gas pressure sensors with a precision of 0.001 MPa. In addition, a gas chromatography made by Shimadzu Scientific Instruments was used to measure the composition of the effluent gas.

The experimental procedures were as follows:

- (1) Locate the coal sample into the triaxial servo-controlled apparatus and set the environmental temperature as 15 °C.
- (2) Vacuum the sample for approximately 24 h to remove the residual air. Apply a confining pressure of 6 MPa to the coal sample.

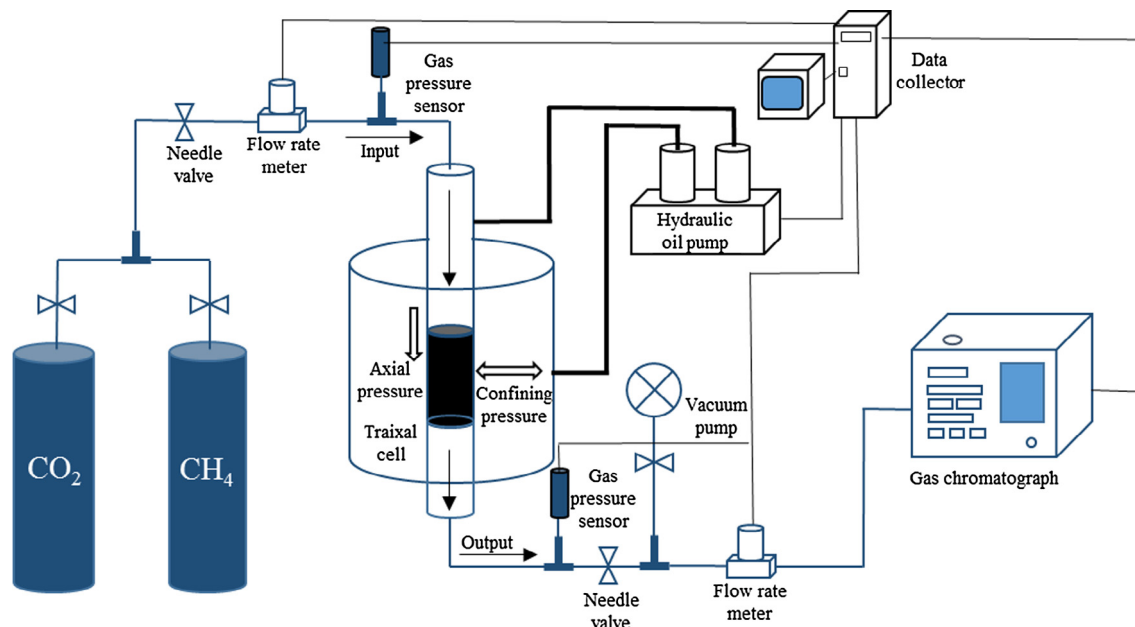


Fig. 1. Schematic of the apparatus.

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